Journal of the Neurological Sciences 383 (2017) 161–165

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

journal homepage: www.elsevier.com/locate/jns

Sensory training with vibration-induced kinesthetic illusions improves proprioceptive integration in patients with Parkinson's disease

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A R T I C L E I N F O

Keywords:
Proprioception
Vibration
Illusory movement
Training
Voluntary movement

A B S T R A C T

The present study investigates whether proprioceptive training, based on kinesthetic illusions, can help in re-educating the processing of muscle proprioceptive input, which is impaired in patients with Parkinson's disease (PD).

The processing of proprioceptive input before and after training was evaluated by determining the error in the amplitude of voluntary dorsiflexion ankle movement (20°), induced by applying a vibration on the tendon of the gastrocnemius-soleus muscle (a vibration-induced movement error). The training consisted of the subjects focusing their attention upon a series of illusory movements of the ankle.

Eleven PD patients and eleven age-matched control subjects were tested. Before training, vibration reduced dorsiflexion amplitude in controls by 4.3° ($P < 0.001$); conversely, vibration was inefficient in PD's movement amplitude (reduction of 2.1°, $P = 0.20$). After training, vibration significantly reduced the estimated movement amplitude in PD patients by 5.3° ($P = 0.01$).

This re-emergence of a vibration-induced error leads us to conclude that proprioceptive training, based on kinesthetic illusions, is a simple means for re-educating the processing of muscle proprioceptive input in PD patients. Such complementary training should be included in rehabilitation programs that presently focus on improving balance and motor performance.

1. Introduction

Muscle proprioceptive information is known to be of prime importance in the sense of posture and movement, and in the regulation of motor activities [1,2]. This peripheral muscle feedback seems to be spared in patients with Parkinson's disease (PD), as found through microneurographic recordings of muscle proprioceptive afferents [3]. By contrast, the central treatment of this sensory feedback is impaired in PD patients as shown, for example, by the higher threshold for detecting passive movements [4,5], localization errors in hand position matching tasks [6], and in altered proprioception-related evoked potentials during passive movements [7]. Changes in the supraspinal processing of proprioceptive input in PD have been demonstrated by analyzing the effect of mechanical vibration applied to the tendon of a muscle stretched during voluntary movements [8,9].

Vibratory stimulation activates muscle spindle afferents, particularly primary endings [10], where the muscle feedback is not only related to the movement performed, but also to the vibration-induced response. In healthy subjects, this increased feedback changes the sense of movement, where the subject has an impression that the movement was performed at a higher velocity, leading to a reduction in the amplitude of the desired movement and a vibration-induced movement error [11,12]. In PD patients, this vibration-induced error is decreased, which indicates an altered processing of proprioceptive sensory information [8,9]. Changes in the cerebro-basal ganglia loop are thought to be responsible for this altered proprioceptive integration [4]. The defective utilization of such proprioceptive information contributes to the movement issues that characterize this disease, notably in terms of postural control [13,14]. Thus, any therapy that could alleviate kinesthetic deficits may be considered important in the treatment of these patients [15].

The present study aimed at improving the integration of muscle proprioceptive inputs by supraspinal structures. For that purpose, PD patients and age-matched healthy subjects completed a training task during which they were asked to focus their attention upon illusory movements that were induced by muscle tendon vibration, in order to identify the illusory direction and velocity. The effect of the training was evaluated by measuring the vibration-induced movement error, as

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https://doi.org/10.1016/j.jns.2017.11.016
Received 9 June 2017; Received in revised form 21 September 2017; Accepted 14 November 2017
Available online 20 November 2017
0022-510X/

Table 1
Patient characteristics.

Patient	Age (years)	Gender	More affected foot	Disease duration (ye {Citation} ars)	STN-DBS duration (months)	UPDRS III on on[†]
1	62	F	R	16	6	15
2	70	M	R	10	6	10
3	56	F	L	11	6	7
4	64	M	L	7	12	9
5	61	F	L	7	36	13
6	66	F	L	5	3	7
7	73	F	L	11	36	20
8	63	M	L	10	12	13
9	65	M	L	13	12	17
10	50	M	L	9	3	9
11	65	F	R	9	36	6

STN-DBS: subthalamic nucleus deep brain stimulation.
UPDRS: unified Parkinson disease rating scale.
[†] With dopa and during stimluation on.

previously described, and we hypothesized that this error would increase after training, only in PD patients, indicating a better use of muscle proprioceptive cues in the perception of ankle movements.

2. Materials and methods

2.1. Subjects

Eleven patients with PD (range 50–73 years; mean ± SD, 63.2 ± 6.2 years; six females), all of whom had stimulating electrodes implanted bilaterally in the subthalamic nucleus, and 11 healthy subjects with no history of neurological or psychiatric disease (range 55–72 years; mean ± SD, 63.3 ± 4.9 years; four females) participated in this study. All patients were tested on their regular anti-Parkinsonian medications and with the deep brain subthalamic nucleus stimulation turned on, providing optimal conditions to reduce bradykinesia [6,15]. Details of the clinical characteristics and basic demographics of the PD patients are listed in Table 1. The study was approved by the local ethics committee and all subjects provided their written, informed consent for the participation in the study.

2.2. Experimental design and protocol

The subjects lay on their back on a comfortable massage table with their feet unsupported. A goniometer was placed on the left foot in healthy subjects, or the foot on the more severely affected side in PD patients, at the level of the malleolus and a mechanical vibrator was positioned on the distal tendon of the gastrocnemius/soleus (GS) muscles; both were kept in place by means of Velcro elastic bands (Fig. 1). At the beginning of the experiment, the subjects experienced a few trials of vibratory stimulation to familiarize them with the equipment used and the sensations of illusory movement.

The subjects were asked to perform active dorsiflexion movements. The movement was first given to the subjects by the experimenter passively moving the ankle joint. The movement consisted of a dorsiflexion of 20° for 2 s, with a beginning and stop signal given by two warning beeps before returning to the starting angle, which was the subject's own anatomically neutral ankle position. The experimenter imposed the same movement five times and the subjects had to focus on both the amplitude and velocity of the movement. The subjects were then asked to reproduce the same movement as accurately as possible three times, with verbal feedback on their performance. After this stage of motor learning, voluntary movements were performed under their own proprioceptive guidance exclusively and no feedback was given on the performance. Three experimental sessions were run: pre-training, training, and post-training. In all sessions, the subjects were required to keep their eyes closed.

The pre- and post-training sessions consisted in 30 dorsiflexions that were voluntarily performed by the subjects either in the absence (non-vibrated, NV, N = 15) or in the presence (vibrated, V, N = 15) of GS tendon vibration, and the vibrations were conducted in a random order. During these trials, the end ankle angle reached at the stop auditory cue was measured (see Fig. 1). Data were recorded using a portable PowerLab system (ADInstruments, New Zealand). After each movement, the subjects rested for 30 s.

In the training session, a second vibrator was placed on the tendon of the tibialis anterior (TA) muscle. The subjects were asked to remain totally relaxed and to focus their attention on the sensation of movement. A series of 40 trials were conducted where illusory movements of the ankle were elicited by activating either the GS (N = 20) or TA (N = 20) vibrating stimulator, in random order. In 10 of these 20 trials, the GS vibratory stimulation was paired with a slow 1° manual stretching of the GS muscle, by the experimenter, in order to increase the velocity of the sensation of illusory dorsal flexion movement. Likewise, in 10 of the 20 trials with TA vibratory stimulation, a slow 1° manual stretching of the TA muscle was imposed to increase the velocity of the sensation of illusory plantar flexion movement. Immediately after each trial, the subjects were asked to verbally report both movement direction (dorsiflexion or a plantar flexion) and whether the perceived movement was of low (no stretching) or high (with stretching) velocity. All the participants (PD and control) felt clear sensations of illusory movement of the ankle joint and the parameters (direction and velocity) were as expected: a dorsiflexion or a plantar flexion when vibration was applied to the tendon of the GS or TA, respectively. Furthermore, for all the participants (PD and control) the velocity was perceived higher during the trials where a 1° stretching of the vibrated muscle was added.

2.3. Mechanical vibration

Vibrations (frequency: 80 Hz; peak-to-peak amplitude: 0.5 mm) were delivered via mechanical vibrators (DC motors with eccentric masses, 1.5 cm in diameter, 4 cm in length, Technoconcept, France).

In the pre- and post-training sessions, during the V trials, vibration lasted for 2 s, i.e. the GS vibrator was turned on and off, on the go and stop auditory cues, respectively. In the training session, the GS or TA vibrator was activated during 8 s, i.e. a time sufficient to induce a clear sensation of ankle movement, but not for too long so as to prevent disagreeable sensations such as exaggerated plantar flexion displacements.

2.4. Statistics

The movement amplitudes measured without and with vibratory stimulation were compared before and after the training session, using a paired *t*-test, in each of the patient and healthy subject groups. As in previous studies [8,9], the vibration induced errors in amplitude were expressed by the ratios of V/NV movement amplitude. The level of significance was set at an alpha of $P \le 0.05$ level (*p* values are given to three decimal places). Finally, the magnitude of the effect was estimated by calculating Cohen's d, where 0.2 is a small magnitude, 0.5 is a medium magnitude, and 0.8 is a large magnitude effect [16]. Statistical analyses were performed using commercially available statistical software (Statistica, USA).

3. Results

The results obtained with one PD patient are shown as an example representative of the population, in Fig. 2. In the pre-training session, the patient underestimated the amplitude of voluntary ankle dorsiflexion performed, since the movement surpassed the target amplitude